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TECHNICAL MEMORANDUM 1532

EXPERIMENTAL INVESTIGATION OF ANTENNA CHARACTERISTICS OF RANDOM LENGTH WIRES WHEN TERMINATED IN A TWO OHM LOAD

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(COORDINATOR)

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PICATINNY ARSENAL
DOVER, NEW JERSEY

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EXPERIMENTAL INVESTIGATION OF ANTENNA CHARACTERISTICS OF RANDOM LENGTH WIRES WHEN TERMINATED IN A TWO-OHM LOAD

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NOVEMBER 1964

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INTRODUCTION

This technical memorandum presents data and results of tests performed to determine the RF power which can be delivered to electroexplosive initiators (blasting caps) when connected to various wire configurations typical of blasting operations and with the entire system exposed to electromagnetic radiation. Five distinct wire patterns were chosen to simulate the random wire inadvertent antennas of typical blasting operations.

This report describes the tests performed and the methods used to test these antennas over the range of frequencies and test conditions as prescribed by the Systems Unit. One point of particular interest was to determine the difference in energy received when the random wire antennas were located on the ground compared to when they were raised three feet off the ground. Also of interest were the characteristics of the diamond antenna when exposed to swept frequencies. All configurations that were found to receive sufficient energy to fire a loaded blasting cap were to be retested with loaded caps.

SUMMARY

This report describes the tests conducted on five specific wire configurations with blasting caps attached, for the purpose of determining their antenna characteristics. These configurations were formed from insulated wire similar to that furnished with M6 Blasting Caps. The five configurations were tested to determine their receiving characteristics by measuring (with suitable instrumentation) the current flowing in the bridgewire of the blasting cap as the result of electromagnetic energy abstracted by the antenna from the impinging field.

The specific configurations tested were:

Diamond Antenna
Eleven-inch folded Dipole Antenna
Thirty-nine foot three-inch, Dipole Antenna
Forty-eight by 24-foot Loop Antenna
Fifty-foot, two-conductor Antenna

These configurations were selected since it is likely that they might occur in blasting operations and thus represent the most susceptible types of configurations (Figures 1-5).

Each configuration was exposed to radio frequency (RF) in two specific positions -- on the ground and three feet above the ground. In all cases, horizontal polarization was employed and each configuration was laid out horizontally and oriented in a direction for maximum RF current in the instrumented bridgewire.

The tests show that -- with the exception of the diamond configuration -- there is considerable reduction (up to 12 db) in received power when the antenna configurations are located on the ground compared to when they are located three feet above the ground. The diamond configuration did not indicate an appreciable difference in received power when the antenna height was varied from three feet down to six inches, although the amount of pickup was enhanced about six db by the addition of a reflector.

Where the configurations are formed by straight or nearly straight pairs of wires they appear to function as half-wave dipoles and as might be expected the maximum bridgewire current occurs at about the calculated half-wave resonant frequency.

The data indicate that it was only feasible, with the RF fields available, to attempt to fire live M6 Blasting Caps in the diamond configuration with a foil reflector added to enhance its effective gain. Eight live blasting caps were detonated by sweeping the high frequency transmitter through a frequency band from 900 to 2,000 Mc. Detonation occurred at 1,260 Mc when the band was swept, starting at the low end of the band; detonation occurred at 1,400 Mc when the band was swept from the high end down.

Data also was obtained on the diamond configuration while sweeping the transmitter through the 900 to 1,000 Mc band at two different rates: 24.5 Mc/sec and at 11 Mc/sec. Bridgewire current response was identical under both the high and low rate, demonstrating that the thermal time constant of the bridgewire and the Q of the configuration are compatible with the high rate of sweep.

Data showing the relationship between frequency and bridgewire current for each antenna are included as well as graphs, where sufficient data was available. The bridgewire current was normalized to 1) the field intensity required to induce NO FIRE current in the field, 2) an arbitrarily selected field intensity of 20 volts/meter (0.1 Mw/cm^2) which can easily be encountered in the field and 3) the current at the maximum available field intensity, and presented as a function of frequency.

CONCLUSIONS

Test results indicate that only the diamond configuration with foil backing can be used to fire live blasting caps at the RF facility at Picatinny Arsenal. All other configurations were incapable of abstracting sufficient energy from the available RF fields to raise the bridgewire current above the NO FIRE level. Data for the antennas has been presented extrapolated to the field intensity required to induce:

1. The NO FIRE current in the bridgewire.
2. The current at a field intensity of 20 volts/meter.
3. The current at the maximum available field intensity.

Both the folded dipole antenna and the 50-foot two-wire antenna appear to be resonant, and abstract maximum RF energy, at their calculated half-wave resonant frequencies.

The effective height of the diamond antenna does not vary appreciably with the actual height above the ground at microwave frequencies, therefore proximity to the earth does not appreciably reduce the susceptibility of configurations of this type.

Detonation of M6 Blasting Caps in the diamond configuration can be accomplished by sweeping the high frequency transmitter through the band of frequencies where the configuration displays maximum pickup capability as long as the rate of sweep is compatible with the Q of the configuration and the thermal time constant of the blasting cap.

RECOMMENDATIONS

The tests in this report were performed on five specific configurations rather than on truly random antenna configurations. It is recommended that further tests be performed on random configurations and that an attempt be made to statistically evaluate the susceptibility of the many possible tactical configurations which can be formed.

DISCUSSION

These tests were conducted to determine the amount of RF power that can be delivered to electroexplosive initiators (blasting caps) when they are connected to various wire configurations typical of blasting operations. It was realized that if random length wires were actually used without an attempt at utilizing defined configurations the tests would necessarily have had to be on a statistical basis. From past experience with blasting caps and their associated connecting wires, five specific antenna configurations were selected as representative of the random wire inadvertent antennas typical of blasting operations.

Appendix C is the test plan for this program and describes the tests and the methods used on the antennas over the range of frequencies and test conditions as prescribed by the Systems Unit.

This section of the report details the antennas tested and in addition includes changes made in the test plan that were indicated to be necessary as the tests proceeded. The five test antennas utilized for this program were:

Diamond Antenna (Figure 1) -- This wire configuration was mounted six inches above a wooden board and exposed to swept frequencies from 900 Mc to 2.0 Gc. Additional tests were performed at spot frequencies to obtain a curve of the envelope of the resonance peaks (interpretation of data) and the field intensity corresponding to each peak. Tests also were performed at 16.4 and 25.4 Mc. These tests were performed with the antenna on the ground and three feet off the ground. Tests also were performed with a metallic foil sheet reflector mounted on the wooden board; common mode measurements also were performed with this configuration.

Folded Dipole - 11 Inch (Figure 2) -- This wire configuration was constructed and exposed to swept frequencie from 500 Mc to 950 Mc. Additional tests were performed at spot frequencies to obtain a curve of the envelope of the resonance peaks (discussion of data) and the field intensity corresponding to each peak. These tests were performed with the antenna on the ground and three feet off the ground. Data was obtained with the blasting machine in and out of the circuit.

Folded Dipole Antenna - 39 feet 3 inches (Figure 3) -- This configuration was constructed and tested at 12 Mc. All four sensors were left in the circuit during tests and the recorder was connected to each in turn. Common mode measurements were performed on each sensor. Tests were performed (a) with the blasting machine out and with the configuration leads open; (b) with the blasting machine connected to the configuration leads; and (c) with the blasting machine out and the configuration leads shorted.

Loop Antenna - 48 feet x 24 feet (Figure 4) -- This configuration was constructed and tested at 4.03, 12, 300, 500, 600 and 700 Mc. All three sensors were left in the circuit during tests and the recorder was connected to each in turn. Common mode measurements were performed on each sensor. Tests were performed: (a) with the blasting machine out and with the configuration leads open; (b) with the blasting machine connected to the configuration leads and (c) with the blasting machine out and the configuration leads shorted. All tests were performed with the antenna located three feet off the ground and on the ground.

Fifty-Foot Two-Conductor Antenna (Figure 5) -- This configuration was constructed and tested at 5.875, 9 and 12 Mc. Tests were conducted with the sensor in the position shown and also with it moved to the center of one wire. Common mode measurements were performed on each sensor. Tests were performed: (a) with the blasting machine out and with the configuration leads open; (b) with the blasting machine connected to the configuration leads and (c) with the blasting machine out and the configuration leads shorted. Tests included the antenna at ground level and three feet off the ground.

Each of the configurations was, in turn, exposed to horizontally polarized RF and orientation was adjusted so that maximum RF current flowed in the bridgewire. The distance from the transmitter to the configuration under test was chosen so that it was at least one wavelength at the transmitted frequency. This was to insure that the tests were being conducted in the far field where standard techniques can be employed to measure the intensity of the radiated field.

The procedure adhered to during tests was:

> The oscillograph recorder was connected to the configuration under test (Appendix C).
>
> The transmitter was turned on and field intensity measurements made.
>
> Galvanometer mechanical zero was noted with the transmitter off.
>
> The transmitter was again turned on and the galvanometer deflection noted.
>
> The bridgewire was then properly short circuited to check for common mode voltages (Appendix D).

INSTRUMENTATION

The instrumented blasting cap or sensor, referred to in the configurations listed in Appendix C, consists of a bare M6 Bridge Plug with a vacuum deposited thermocouple (VDT) mounted within 0.003-inch of the bridgewire. Each sensor is encased within a brass case simulating the shell of the blasting cap. During tests the bridgewire leads are connected to the configuration in question. The leads emanating from the VDT are run through balanced shielded wire to a Midwestern type 560-C5 recorder. It should be noted that during tests a procedure was established to assure that the instrumentation and leads were not in themselves picking up RF.

The sensitivity of this instrumentation is such that 5 Ma of bridgewire current can be resolved. This is equivalent to monitoring currents 1/40 of the NO FIRE current of the M6 Blasting Cap and therefore permits extrapolation of data to field intensities of 40 times the test environment.

Each of the instrumented M6 sensors was calibrated in the laboratory by conducting 10, 20 and 30 Ma of direct current through the bridgewire and recording the deflection of the galvanometer of the Midwestern Recorder (the calibration data appears in Table 2). Since the thermocouple is basically a temperature sensing device, and since the temperature rise of the bridgewire is directly proportional to the power supplied to the bridgewire, the thermocouple sensor therefore acts as a square law detector -- output voltage is proportional to the square of bridgewire current. With the data obtained in the laboratory one can establish a sensor constant K which relates galvanometer deflection to bridgewire current. This relationship is given by:

$$I = \left(\frac{D}{K}\right)^{1/2}$$

where D = Galvanometer deflection in mm
I = Bridgewire current in ma
K = Sensor constant in mm/ma^2

For a given galvanometer deflection during tests, the formula permits the determination of the amount of DC equivalent current flowing in the bridgewire over the range of test frequencies.

INTERPRETATION OF DATA

Diamond Antenna (Figure 1) -- The diamond antenna displayed multi-resonant phenomena which is demonstrated by the many current maximums occurring throughout the frequency range from 0.930 to 2.0 Gc. Graph 1 clearly indicates that this configuration is equally susceptible to four frequencies (1.06, 1.2, 1.265 and 1.49 Gc). It must be emphasized that measurements were made at reduced transmitter power to protect the instrumented sensor from burnout. Graph 2 and 3 are a result of the extrapolation of measured sensor current to the maximum transmitter power available at the facility. These graphs clearly indicate that it is not possible to reach the NO FIRE level (200 ma) for the M6 Blasting Cap unless aluminum foil is placed six inches below the diamond antenna. This foil, in effect, increases the effective gain of the diamond antenna by about 6 db. In addition, Graph 2 shows the relationship between the amount of current flowing in the bridgewire when the antenna is located both three feet above the ground and also six inches above the ground. It is interesting to note that the diamond configuration is nearly as sensitive with the antenna located six inches above the ground as it is when it is located three feet above the ground. This did not occur for the low frequency configurations. This phenomena can be explained by noting that for a given length of wire, exposed to horizontal radiation, the vertical angle of maximum radiation varies as a function of frequency. At the lower frequencies where the height of the antenna (or wire) above ground is small with respect to wavelength, the vertical angle of maximum radiation is extremely high giving rise to an effective antenna gain which is low compared to its free space gain. However, for a given height above the ground, as the frequency is raised, the angle of maximum radiation tilts downward resulting in an effective antenna gain which approaches free space gain and can actually exceed free space gain by a factor of two, which occurs when the reflected wave completely reinforces the direct wave (Table 3a and 3b).

Graph 3 is a plot of bridgewire current extrapolated to maximum available facility power vs. frequency for the diamond antenna with a foil reflector. The addition of the reflector to the configuration, in effect, increases the gain of the antenna approximately 6 db. This added gain was sufficient to raise the current above the NO FIRE level at two frequencies, 1.260 Gc and 1.4 Gc. Eight live M6 Blasting Caps were exploded to verify the existence of sufficient fields to detonate live caps. Data was also obtained on the diamond configuration while sweeping the transmitter through the 900 to 1,000 Mc band at two different rates, at 24.5 Mc/sec and at 11 Mc/sec. Bridgewire current response was identical under both the high and low rate, demonstrating that the thermal time constant of the bridgewire and the Q of the configuration are compatible with the high rate of sweep.

Eleven-Inch Folded Dipole (Figure 2) -- Data resulting from irradiating the 11-inch folded dipole are in Table 4. Graph 4 shows bridgewire current normalized to 20 volts per meter field intensity vs. frequency. The most susceptible condition occurs at a frequency of 540 Mc, with the antenna located three feet above the ground, when the antenna is not terminated with the blasting machine but with the connecting leads short circuited. Fifty-seven volts per meter is required to raise the current up to the NO FIRE level for the M6 Blasting Cap. When this configuration was placed on the ground the current was reduced to zero at the most susceptible frequency.

Thirty-Nine Foot Folded Dipole (Figure 3) -- The data using the 39-foot folded dipole antenna are in Table 5. The data indicate that the most susceptible condition occurs when the blasting machine is connected in the IN position with the antenna located three feet above the ground (Figure 3). The sensor indicating the highest susceptibility is Sensor #198, located in Position 3 of Figure 3. It should be noted however, that Sensor #1786, which is located in Position 2, also presents a high degree of susceptibility. Theoretically, the sensor located in Position 2 should be the most susceptible. It is felt that the current distribution along the dipole is affected by the asymmetrical arrangement of the M6 sensors in the antenna, thereby shifting the current maximum point to the right of center. Thirty-eight volts per meter is required to raise the bridgewire current to the NO FIRE level.

The energy abstracted by this configuration was considerably reduced when the antenna was placed on the ground.

Forty-Eight Foot Loop Antenna (Figure 4) -- For the 48 x 24 foot configuration maximum current was indicated at 12 Mc with the instrumented sensor in Position 1 with the antenna located three feet above the ground (Table 6).

Thirty-one volts per meter is required to raise the bridgewire current to the NO FIRE current level.

The power received by this configuration went to zero when the antenna was placed on the ground.

Fifty-Foot Two-Conductor Antenna (Figure 5) -- The 50-foot configuration receives maximum energy at 9 Mc, its theoretical half-wave resonant frequency. Maximum current is experienced with the sensor located in Position 2 and the antenna three feet off the ground (Table 7). Eighteen and one-half volts per meter is required to detonate M6 Detonating Caps (Graph 5).

The power received by this configuration went to zero when the antenna was placed on the ground.

Table 8 summarizes the minimum field intensity necessary to raise the bridgewire current to NO FIRE level of the M6 Blasting Cap for all configurations tested. In addition, minimum safe distance of each configuration is noted for a typical transmitter setup.

REFERENCES

1. John D. Kraus, Antennas, Electrical and Electronic Engineering Series, McGraw-Hill Publishing Company, New York, 1950.

2. Abraham Grinoch, Hazards of RF to Ordnance, Paper presented at National Winter Convention on Military Electronics I.E.E.E., Los Angeles, California, Page 14 and Figure 12, February 1964.

3. Richard G. Satz, M18A1 Anti-Personnel Mine RF Susceptibility Report, Technical Services Laboratory Report 71-63, Picatinny Arsenal, May 1963.

APPENDICES

APPENDIX A

TABLES

TABLE 1

TRANSMITTING EQUIPMENT

Frequency	Transmitter Nomenclature	Antenna	Power (watts)
4 Mc - 30 Mc	BC-339	$\lambda/2$ Dipole	1,000
350 Mc - 2 Gc	350 Mc - 10.4 Gc Xmtr	Log Periodic	250

FIELD INTENSITY EQUIPMENT

Frequency	Transmitter Nomenclature	Antenna
4 Mc - 30 Mc	Empire, NF105	Loop, LP-105
350 M - 16 c	Empire, NF105	Dipole, DM-105-T3
16 c - 26 c	Empire, NF112	Log Periodic, AT-112

TABLE 2

CALIBRATION OF VACUUM DEPOSITED THERMOCUPLE SENSOR

Sensor No.	Deflection (mm) Vs Bridgewire (ma) 10	20	30	Calibration Constant K (mm/(ma)^2)
1781	1.5	5.0	11.0	1/80
1785	1	3.5	7	1/160
1786	1	5	10.5	1/86
192	0.75	2.5	4.75	1/190
193	0.5	2.0	4.0	1/225
198	0.5	2	4.5	1/200

Instrumented Blasting Cap

$D = KI^2$ where D = Galvanometer deflection in mm
K = Calibration constant
I = Bridgewire current

TABLE 3a

Diamond Antenna - Without Foil (Fig. 1, Appendix C)

Freq. (Gc)	Bridgewire Current (Ma) Antenna 3ft. off Ground		Bridgewire Current (Ma) Antenna 6" off Ground		Test Field Intensity Volts/Meter	Bridgewire Current (Ma) Normalized to 20v/m FI Antenna 3' off Ground		Bridgewire Current (Ma) Normalized to 20v/m FI Antenna 6" off Ground		Bridgewire Current (Ma) Extrapolated to max. Trans FI Antenna 3' off Ground		Bridgewire Current (Ma) Extrapolated to max. Trans FI Antenna 6" off Ground	
	Is	Icm	Is	Icm		Is	Icm	Is	Icm	Is	Icm	Is	Icm
1.0	51	0	25	0	20.9	49	0	24	0	50	0	28.5	0
1.06	91	0	68	0	11.7	156	0	117	0	90	0	74	0
1.13	95	0	49	0	15.9	125	0	64	0	106	0	56.5	0
1.145	49	0	28	0	17.4	57	0	45	0	57	0	32.5	0
1.19	63	0	57	0	13.8	92	0	84	0	71	0	64	0
1.2	87	0	74	0	12.3	143	0	122	0	93	0	90	0
1.22	45	0	38	0	10.9	83	0	70	0	47.5	0	45	0
1.235	45	0	35	0	10.9	83	0	65	0	53	0	40	0
1.265	95	0	79	0	11.9	160	0	135	0	182	0	151	0
1.275	49	0	45	0	12.6	80	0	73	0	63.5	0	53	0
1.29	45	0	28	0	19.9	46	0	29	0	53	0	36.5	0
1.32	84	0	53	0	19.9	85	0	54	0	100	0	62,5	0
1.345	33	0	33	0	15.8	42	0	42	0	44	0	34	0
1.41	33	0	25	0	14.5	46	0	35	0	38.5	0	29	0
1.49	74	0	73	0	9.9	151	0	105	0	168	0	166	0
1.492	64	0	43.5	0	9.3	135	0	74	0		0		0
1.52	14	0	14	0	15.8	18	0	18	0	49.5	0	16	0
1.82	0	0	0	0	3.5	0	0	0	0	0	0	0	0
2.02	23.5	0	0	0	12.3	38	0	0	0	55	0	0	0

I_s = I signal

I_{cm} = I common mode

TABLE 3b

Diamond Antenna (Figure 1, Appendix C)

Antenna 3 feet above ground and 6 inches above board with aluminum foil reflector

Frequency (Gc)	Tests F.I. (volts/meter)	Bridgewire Current (Ma)		Bridgewire Current Ma Extrapolated to max. Trans. F.I.	
		I_s	I_{cm}	I_s	I_{cm}
0.930		23.5	0	70.5	0
0.945		49.0	0	145	0
0.950		62.0	0	183	0
0.961		33.5	0	100	0
0.980		20.0	0	56	0
0.992		15.5	0	45	0
1.01	5.9	25.5	0	74	0
1.025	4.2	55.0	0	149	0
1.05	5.9	23.5	0	65	0
1.07		22.0	0	61	0
1.1		46.5	0	130	0
1.101	5.4	49.0	0	137	0
1.13		25.5	0	71	0
1.15		34.5	0	95	0
1.18	6.3	63.0	0	175	0
1.19	5.0	27.0	0	82	0
1.22		28.0	0	83	0
1.25	8.0	75.0	0	222	0
1.275	7.1	23.5	0	76	0
1.3	10.2	34.5	0	107	0
1.32	10.2	61.0	0	190	0
1.345	10.3	18.0	0	67	0
1.365		28.0	0	92	0
1.395	6.5	61.0	0	210	0
1.41	4.6	29.0	0	61	0
1.45	5.2	28.0	0	52	0
1.465	7.4	59.0	0	180	0
1.5	7.4	22.0	0	67	0

I_s = I signal I_{cm} = I common mode

TABLE 4

ELEVEN INCH FOLDED DIPOLE ANTENNA (Figure 2, Appendix C)

Frequency (Ma)	Pos. and Ser No. of Sensor	Field Intensity	Bridgewire Current (Ma)						Bridgewire Current (Ma) Extrapolated to 20 v/m F.I.						Remarks
			3' off ground			On ground			3' off ground			On ground			
			I_s	I_{cm}	Net I_s	I_s	I_{cm}	Net I_s	I_s	I_{cm}	Net I_s	I_s	I_{cm}	Net I_s	
500	193	17.8	26.4	0	26.4				30.0	0	30.0				1. Sensor located at one end.
540	193	7.9	26.4	0	26.4	-	-	-	67.0	0	67.0	-	-	-	
540	193	21.0	-- -	0	----	0	0	0	----	-	----	0	0	0	2. Antenna located 31 feet from transmitter antenna.
590	193	11.75	28.0	0	28.0	0	0	0	47.5	0	47.5	0	0	0	
810	193	23.5	----	0	----	15.0	0	15.0	----	-	----	12.8	0	12.8	
870	193	23.5	36.5	0	34.5	14.2	0	14.2	28.3	0	28.3	12.8	0	12.0	3. Only the sensor was connected to the antenna.
950	193	26.5	14.2	0	14.2	-	-	-	10.8	0	10.8	----	-	----	

I_s = I signal

I_{cm} = I common mode

TABLE 5

THIRTY-NINE FOOT THREE INCHE FOLED DIPOLE ANTENNA (Figure 3, Appendix C)

Frequency (Mc)	Field Intensity and Ser. No. of Sensor	Bridgewire Current (Ma)						Bridgewire Current (Ma) Extrapolated to 20 v/m F.I.						Circuit Arrangement	Remarks
		3' off ground			on ground			3' off ground			on ground				
		I_s	I_{cm}	Net I_s	I_s	I_{cm}	Net I_s	I_s	I_{cm}	Net I_s	I_s	I_{cm}	Net I_s		
193	6.84	37.5	34.5	14.2	0	0	0	111.0	97.0	41.5	0	0	0	Short	NOTE. Short means BM disconnected and leads shorted No Short Same as short but leads open BM in means connected as shown in Figure 3, Appendix C. BM means blasting machine (Electric Generator)
	6.84	0	0	0	0	0	0	0	0	0	0	0	0	No short	
	6 84	20.0	0	20.0	0	0	0	54.0	0	59.0	0	0	0	BM in	
1,786	6.84	39.0	23.5	31.0	8.95	8.95	0	115.0	69.[illegible]	92.0	26.5	26.5	0	Short	
	6.84	8.95	0	8.95	15.5	8.95	12.7	26.5	0	26.4	45.5	26.5	37.3	No short	
	6.84	51.0	31.0	40.0	8.95	8.95	0	150.0	92.0	117.0	26.5	26.5	0	BM in	
196	6.84	74.5	48.5	57.0	20.0	14.2	14.2	218.0	142.0	167.0	59.0	41.5	41.5	Short	
	6.84	20.0	20.0	0	22.5	14.2	17.3	59.0	59.0	0	66.0	41.5	51.0	No short	
	6.84	94.0	58.0	73.5	20.0	14.2	14.2	275.0	172.0	215.0	59.0	41.5	41.5	BM in	
1,783	6.84	0	0	0	0	0	0	0	0	0	0	0	0	Short	
	6.84	0	0	0	0	0	0	0	0	0	0	0	0	No short	
	6.84	8.95	8.95	0	8.95	8.95	0	26.5	26.5	0	26.5	26.5	0	BM in	

I_s = I signal
I_m = I common mode

TABLE 6

FORTY-EIGHT FEET BY TWENTY-FOUR INCH LOOP ANTENNA (Figure 4, Appendix C)

Frequency (Mc)	Position and Ser. No. of Sensor	Field Intensity	Bridgewire Current (Ma) 3' off ground I_s	I_{cm}	Net I_s	Bridgewire Current (Ma) on ground I_s	I_{cm}	Net I_s	Bridgewire Current (Ma) Extrapolated to 20 v/m F.I. 3' off ground I_s	I_{cm}	Net I_s	Extrapolated on ground I_s	I_{cm}	Net I_s	Circuit Arrangement
12	189	3,23	20,0	0	0	0	0	0	124,0	0	0	0	0	0	Short
			0	0	0	0	0	0	0	0	0	0	0	0	No short
			11,0	0	0	0	0	0	87,0	0	0	0	0	0	BM in
12	1,786	[illegible]	9,0	0	0	0	0	0	56,0	0	0	0	0	0	Short
			12,6	0	0	0	0	0	78,0	0	0	0	0	0	No short
			9,0	0	0	0	0	0	56,0	0	0	0	0	0	BM in
12	193	3,23	0	0	0	0	0	0	0	0	0	0	0	0	Short
			11,0	0	0	0	0	0	87,0	0	0	0	0	0	No short
			0	0	0	0	0	0	0	0	0	0	0	0	BM in
400	1,785	3,55	0	0	0	0	0	0	0	0	0	0	0	0	All
	1,782	and	0	0	0	0	0	0	0	0	0	0	0	0	circuit
	192	5,01	0	0	0	0	0	0	0	0	0	0	0	0	positions
400	Same	5,75	0	0	0	0	0	0	0	0	0	0	0	0	All
			0	0	0	0	0	0	0	0	0	0	0	0	circuit
			0	0	0	0	0	0	0	0	0	0	0	0	positions
600	Same	4,07	0	0	0	0	0	0	0	0	0	0	0	0	All circuit
		6,45	0	0	0	0	0	0	0	0	0	0	0	0	positions
4,03	1,785	4,57	12,6	0	0	0	0	0	56,0	0	0	0	0	0	See
	1,782		0	0	0	0	0	0	0	0	0	0	0	0	Note
	192		13,8	0	0	0	0	0	61,0	0	0	0	0	0	B

NOTE A

NOTES: 1. Short means BM disconnected and leads shorted.
2. No short: Same as short but leads open.
3. BM means: connected as shown in Figure 4, Appendix C.
4. BM means: Blasting machine (Electric Generator)

NOTE B

These tests made in Short circuit position only.

I_s = I signal

I_{cm} = I common mode

Table 7

(Figure 5, Appendix C)

50 foot No. 18 Wire - 2 Conductor Antenna

Freq.	Position and Ser. No of Sensor	Field Intensity	Bridgewire Currend (Ma) 3' Off Ground I_s	I_{cm}	Net I_s	On Ground I_s	I_{cm}	Net I_s	Bridgewire Current Extrapolated to 20v/m F.I. 3' Off Ground I_s	I_{cm}	Net I_s	On Ground I_s	I_{cm}	Net I_s	Circuit Arrangement	Remarks
5.875	192	7.24	0	0	0	0	0	0	0	0	0	0	0	0	Short	Sensor at one End.
	192	7.24	0	0	0	0	0	0	0	0	0	0	0	0	No Short	
	192	7.24	0	0	0	3.16	0	3.76	0	0	0	10.6	0	10.6	BM In	
9.0	192	4.12	43.5	0	43.5	0	0	0	2110	0	210.0	0	0	0	Short	
	192	4.12	0	0	0	0	0	0	0	0	0	0	0	0	No Short	
	192	4.12	10.6	0	10.6	0	0	0	52.0	0	52.0	0	0	0	BM In	
12.0	192	4.84	3.3	0	3.3	0	0	0	13.8	0	13.8	0	0	0	Short	
	192	4.84	15.0	0	15.0	0	0	0	61.0	0	61.0	0	0	0	No Short	
	192	4.84	10.6	0	10.6	0	0	0	44.0	0	0	0	0	0	BM In	
5.875	192	7.24	13.0	0	13.0				37.0	0	37.0				Short	Sensor in
	192	7.24	10.6	0	10.6				30	0	30.0				BM In	
9.0	192	4.90	53.0	0	53.0				220.0	0	220.0				Short	
	192	4.90	42.0	0	42.0				174.0	0	174.0				BM In	
12.0	192	4,62	15.0	0	15.0				66.0	0	66.0				Short	
	192	4.62	10.6	0	10.6				46.5	0	46.5				BM In	

I_s =) signal

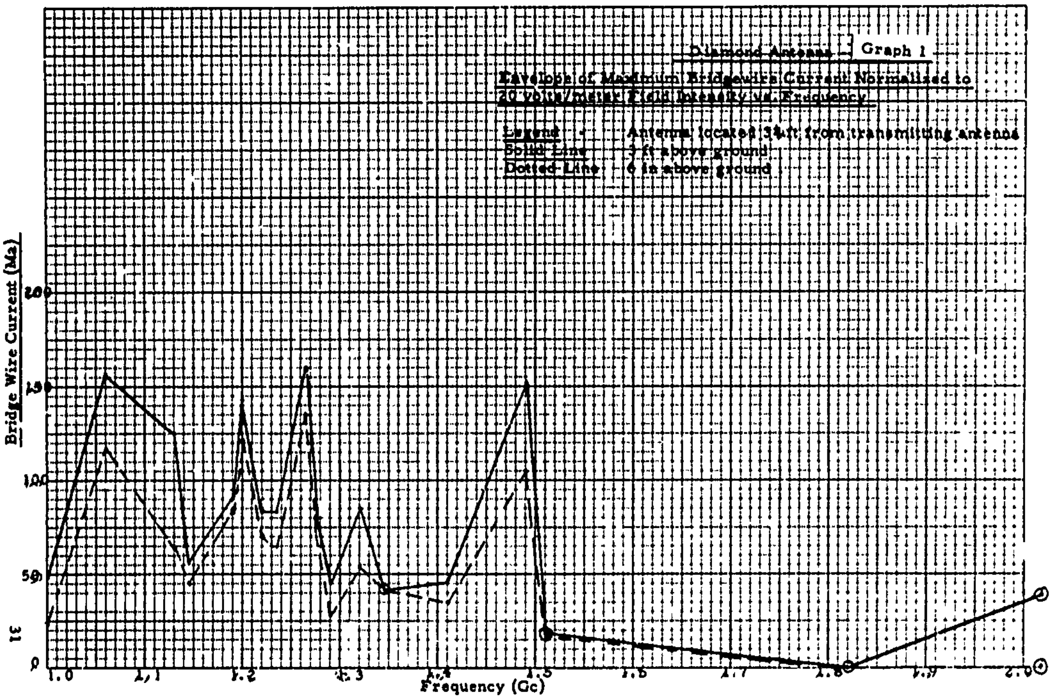
I_{cm} =) common mode

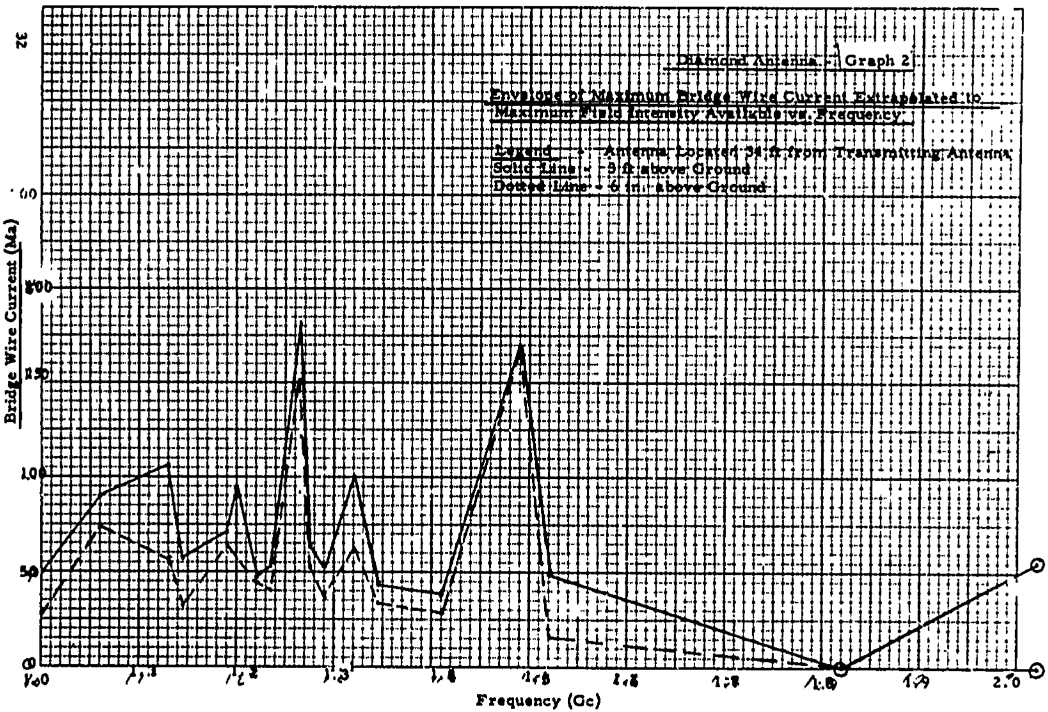
TABLE 8

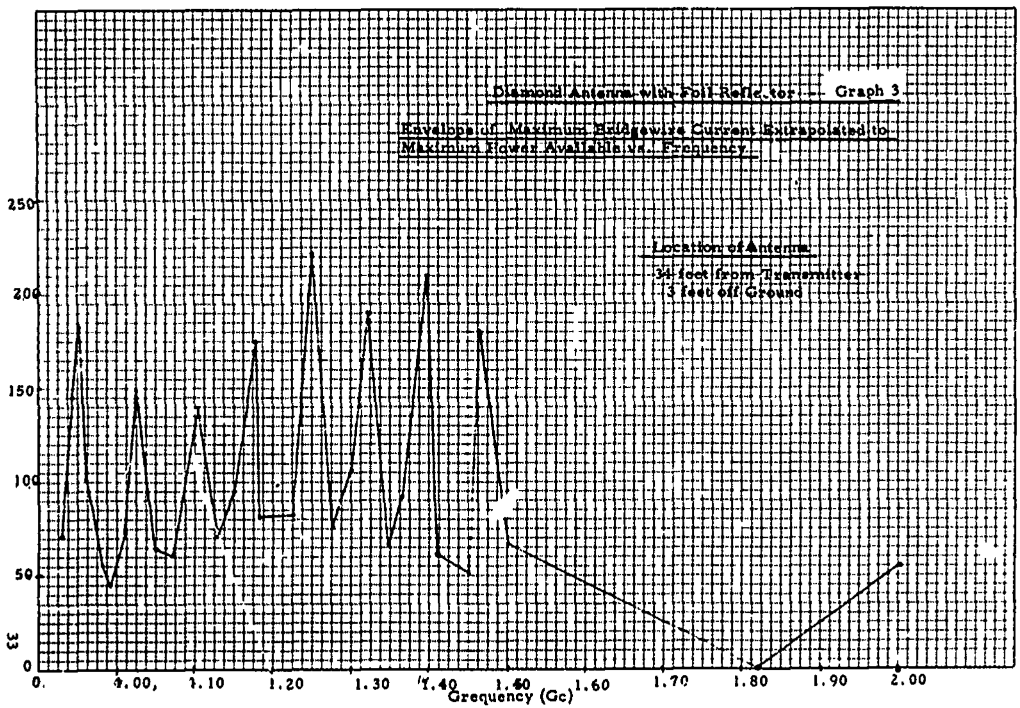
Configuration	Frequency	Distance From Transmitter Antenna	Minimum F.I. to Reach Statistical 5% Firing Probability Level (No-Fire) Level of 200 Ma
Diamond Antenna (Figure 1, Appendix C)	1.265 Gc without foil	30 ft.	25.0 v/m
	1.25 Gc with foil	30 ft.	31.3 v/m
11 in. Folded Dipole Antenna (Figure 2, Appendix C)	540 Mc	30 ft	60 v/m
39 ft. Folded Dipole Antenna (Figure 3, Appendix C)	12 Mc	100 ft.	38.5 v/m
48 ft x 24 ft. Loop Antenna (Figure 4, Appendix C)	12 Mc	100 ft.	31.0 v/m
50 ft. #18 Wire Conductor Antenna (Figure 5, Appendix C)	9 Mc	100 ft.	18.5 v/m

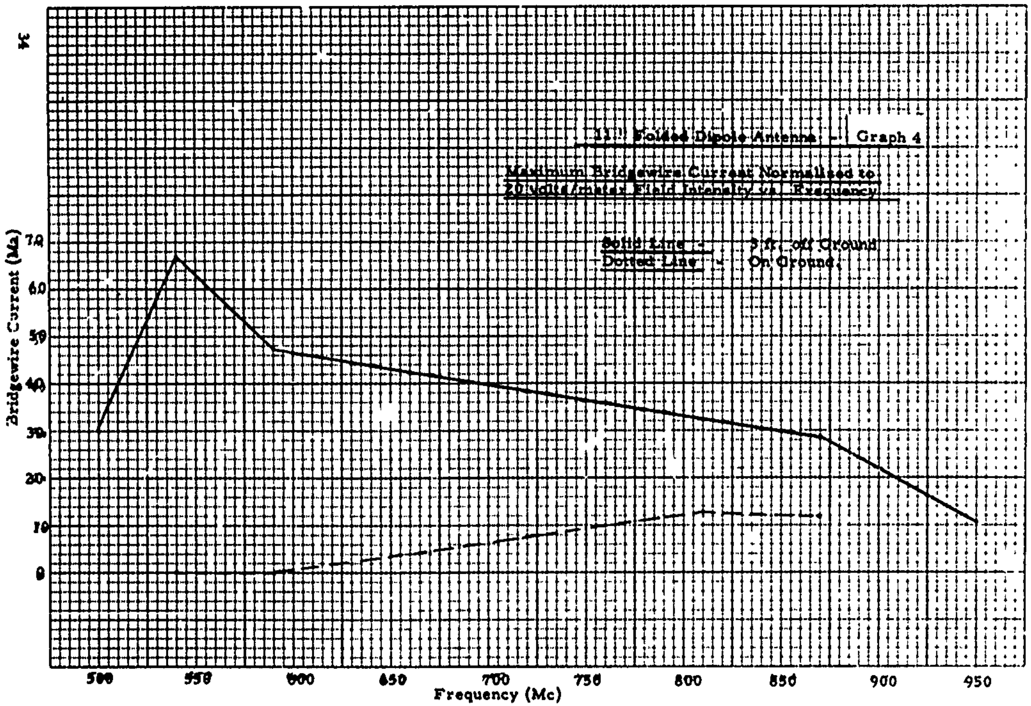
APPENDIX B

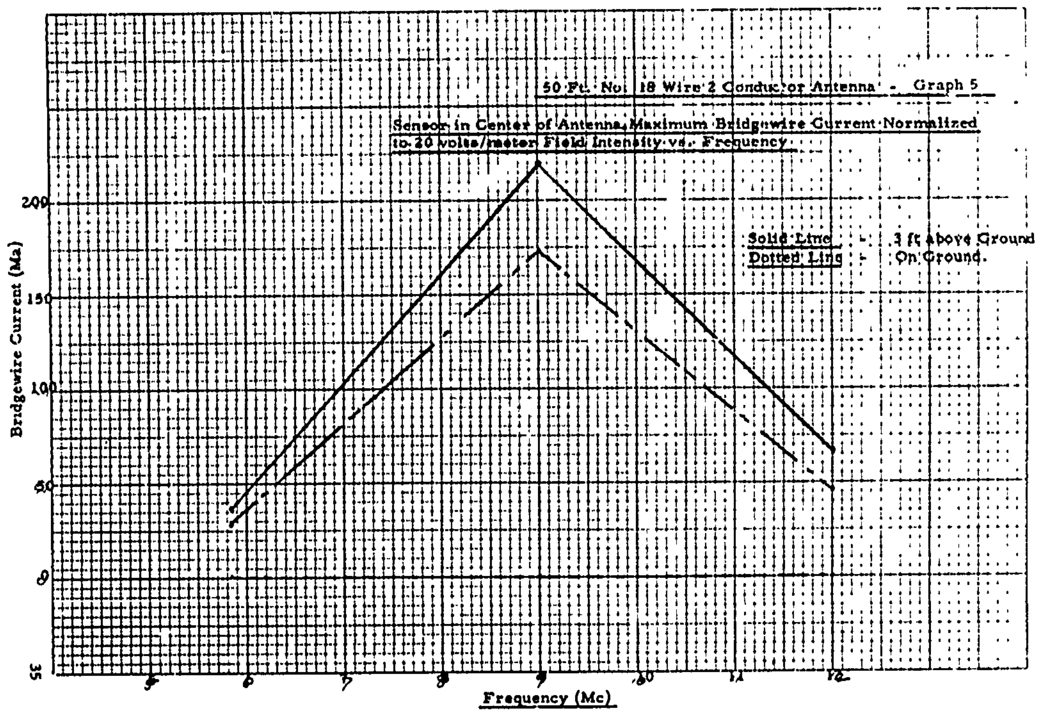
GRAPHS


Diamond Antenna
Graph 1
Envelope of Maximum Bridgewire Current Normalized to 20 volts/meter Field Intensity vs. Frequency
Legend - Antenna located 3½ ft from transmitting antenna
Solid Line 3 ft above ground
Dotted Line 6 in above ground
Bridge Wire Current (Ma)
200
150
100
50
0
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Frequency (Gc)


Diamond Antenna - Graph 2
Envelope of Maximum Bridge Wire Current Extrapolated to Maximum Field Intensity Available vs. Frequency
Legend - Antenna Located 34 ft from Transmitting Antenna
Solid Line - 3 ft above Ground
Dotted Line - 6 in. above Ground
Bridge Wire Current (Ma)
Frequency (Gc)
2.0


Diamond Antenna with Foil Reflector — Graph 3
Envelope of Maximum Bridgewire Current Extrapolated to Maximum Power Available vs. Frequency
Location of Antenna
34 feet from Transmitter
3 feet off Ground
250
200
150
100
50
0
0.
1.00
1.10
1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
2.00
Frequency (Gc)


11" Folded Dipole Antenna - Graph 4
Maximum Bridgewire Current Normalized to
20 volts/meter Field Intensity vs. Frequency
Solid Line - 3 ft. off Ground
Dotted Line - On Ground.
Bridgewire Current (Ma)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
500
550
600
650
700
750
800
850
900
950
Frequency (Mc)


50 Ft. No. 18 Wire 2 Conductor Antenna - Graph 5
Sensor in Center of Antenna, Maximum Bridgewire Current Normalized to 20 volts/meter Field Intensity vs. Frequency
Solid Line - 3 ft above Ground
Dotted Line - On Ground.
Bridgewire Current (Ma)
200
150
100
50
35
5
6
7
8
9
10
11
12
Frequency (Mc)

APPENDIX C

TEST PLAN

OBJECTIVE

This test plan is based upon a plan written by the Systems Unit and intends to determine the antenna characteristics of various types of random length wires when terminated in two ohms impedance and exposed to an RF environment over the frequency range of 5.0 Mc to 2 Kmc. To simulate random length wires, various types of wire antennas are chosen that are characteristic of configurations that may be found in blasting operations and also are likely to experience the most RF current.

The objective will be accomplished by terminating the antennas in an inert M6 Blasting Cap which will be instrumented with a vacuum deposited thermocouple RF sensor. The antenna current experienced, as a result of the RF environment, will be measured utilizing the RF sensor and a recording oscillograph. This will permit determination of the antenna receiving characteristics of the various antennas.

1. Antennas -- The characteristics of random length wires as receiving antennas when terminated in a two ohm load, will be evaluated using the antenna configurations (Figures 1-5):

> Ten-Feet M6 Blasting Cap wires formed into a diamond configuration with 26-inch width -- Test from 900 Mc to 2.0 Kmc (Sweep)
>
> Folded dipole resonant at about 500 Mc -- Test from 350-900 Mc (Sweep)
>
> Folded dipole resonant at about 12 Mc -- Test at 12 and 500 Mc
>
> A loop antenna at 500 Mc and 12 Mc -- Test at 12 and 500 Mc
>
> Fifty-feet of No. 18 wire, two conductor -- Test at 5.0 Mc, 9.0 Mc and 12.0 Mc

2. Instrumentation -- The instrumentation to be utilized in evaluating the above antennas is:

> Each antenna will be terminated in an inert M6 Blasting Cap which will be instrumented with vacuum deposited thermocouple RF sensor.

A Midwestern type 560-C5 oscillograph recorder will be used to record the vacuum deposited thermocouple RF sensor output.

3. Calibration of Instrumentation -- The instrumented inert M6 Blasting Caps will be calibrated, while terminated in their respective recording oscillograph galvanometer channels, at 10, 20 and 30 milliamperes direct current.

4. Test Configurations

Ten feet M6 Blasting Cap lead wires formed into the shape of a diamond will be oriented to obtain maximum RF current in the M6 Blasting Cap bridgewire.

The 500 Mc folded dipole and loop antennas, with M6 Blasting Caps attached, will be laid out horizontally in direction of maximum RF current in the instrumented M6 bridgewires. Tests will be performed with:

Wires open on end opposite blasting caps

Firing Device on end opposite blasting caps

The 12 Mc folded dipole and loop antennas, with inert M6 Blasting Caps attached, will be laid out horizontally, in the direction for maximum RF current in the instrumented M6 bridgewires. Tests will be performed with:

Wires open on end opposite blasting caps

Firing Device on end opposite blasting caps

Fifty-feet No. 18 wire, two conductor, with instrumented inert M6 Blasting Cap attached, will be laid out horizontally in the direction for maximum RF current in the M6 bridgewire. Tests will be performed with:

Wires open on end opposite blasting cap

Firing Device on end opposite blasting cap

NOTE -- Antenna configurations will be evaluated:

While lying on the ground
While suspended three feet off the ground

5. Testing Live M6 Blasting Caps -- If the test results of any or all antenna configurations prove favorable in regards to activating a live M6 Blasting Cap, an attempt will be made to fire a number of M6 Blasting Caps using those antenna configurations found favorable for this purpose.

6. Frequencies -- Evaluation of the various antennas will be conducted at the following frequencies:

5.0 Mc
8.0 Mc
9.0 Mc
11 Mc
12 Mc
13 Mc
350 Mc - 900 Mc (Sweep)
900 Mc - 2 Kmc (Sweep) Resonances will be investigated

7. Polarization -- Testing of the random length wires will be performed at the frequencies found in paragraph 6, using horizontal polarization.

8. RF Environment -- Testing of the random length wires will be conducted in the maximum fields capable of being generated at the RF hazards facility.

9. Data Analysis -- This will be analyzed to determine:

Characteristics of the random length wires as receiving antennas

Receiving characteristics of the antennas when lying on the ground vs. those when the antennas are three feet off the ground

10. Final Test Report -- This report will present the test results on the various antennas and will utilize a standard report format.

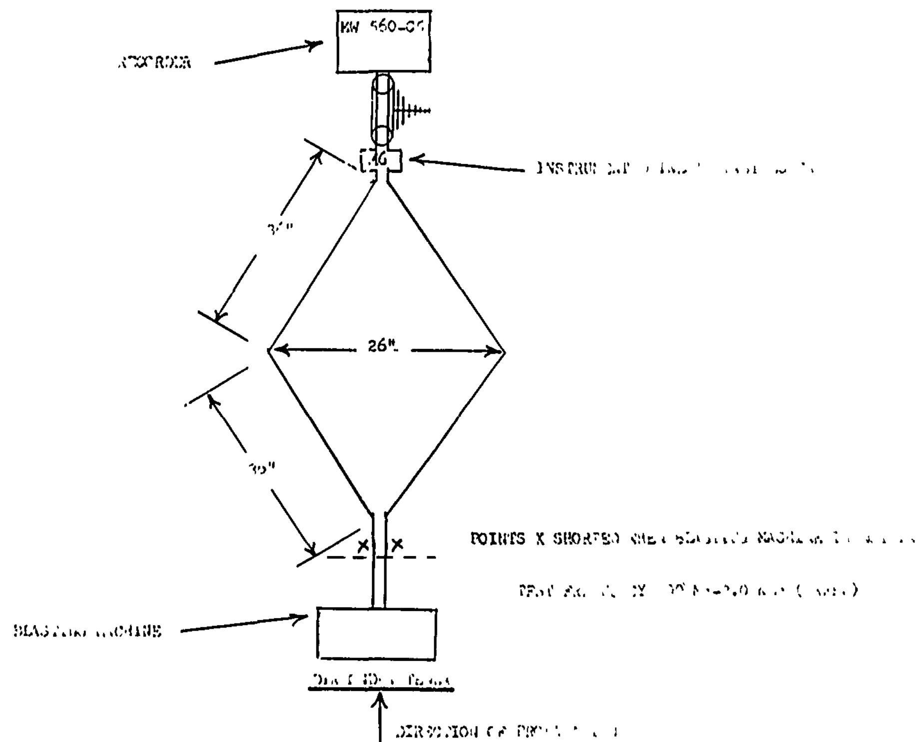
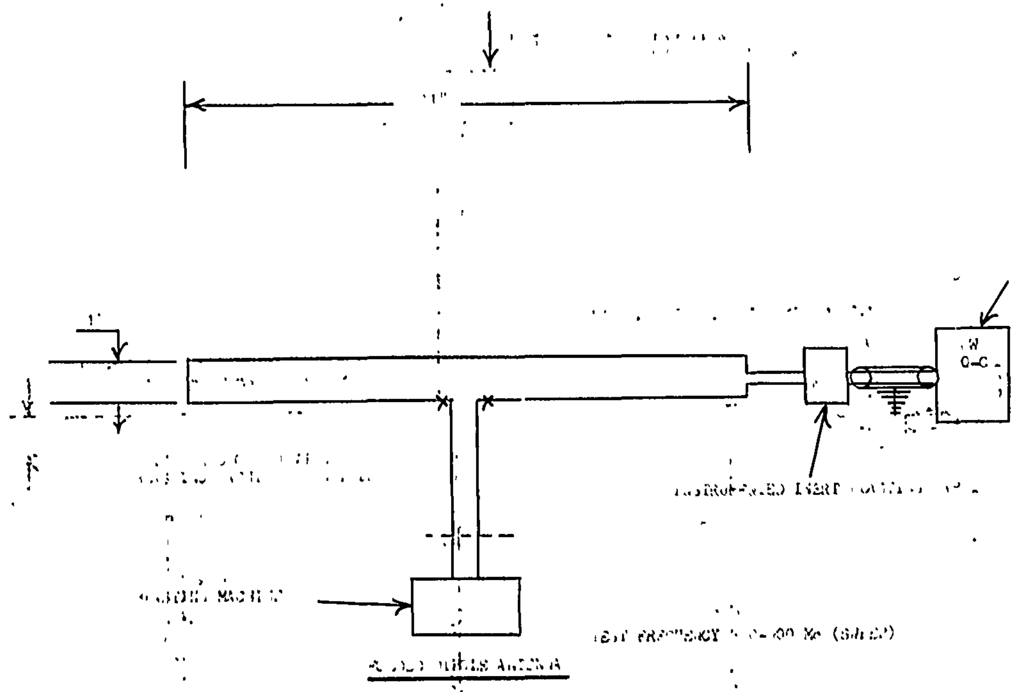
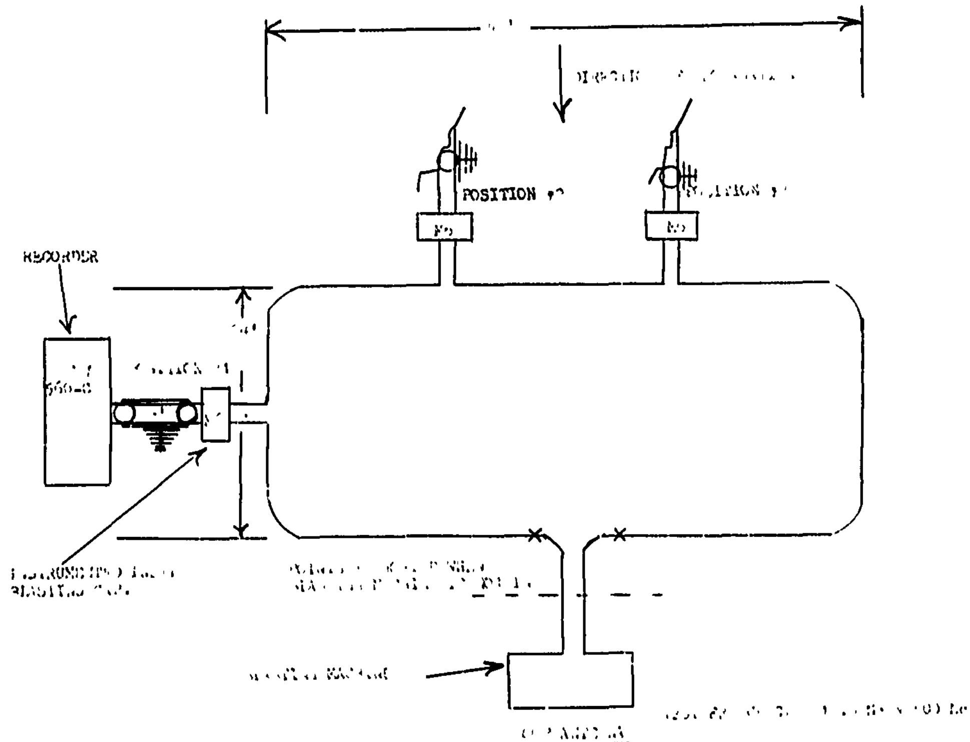
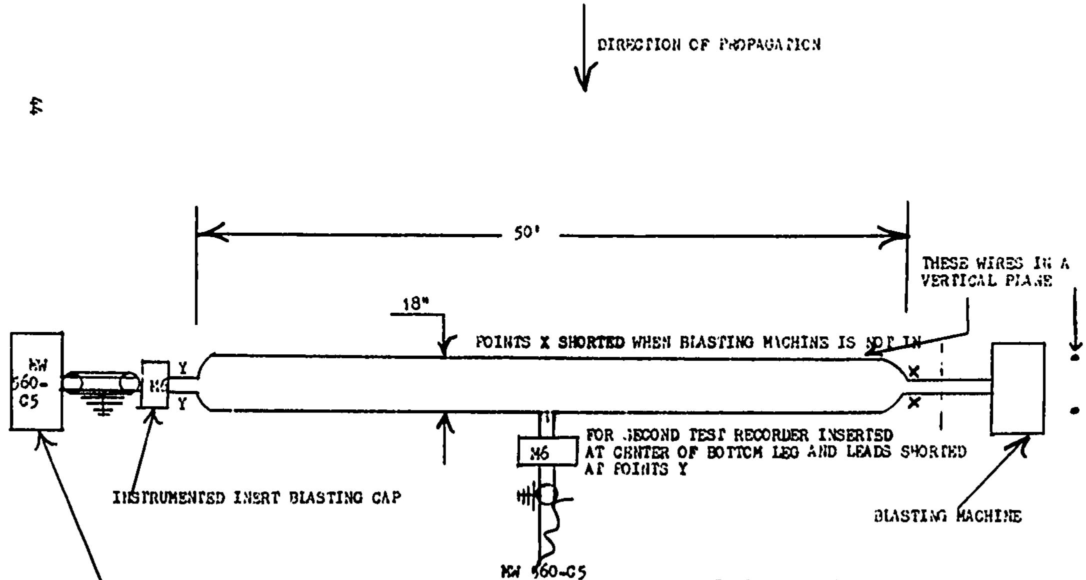


FIGURE 1




POSITION #2
RECORDER



TEST FREQUENCIES: 5.0 Mc, [illegible]

50 FT. #18 WIRE 2 CONDUCTOR ANTENNA

FIGURE 5

APPENDIX D

COMMON MODE REJECTION

COMMON MODE REJECTION

To have current flow through a bridgewire, a potential difference must exist across the bridgewire. When an output signal is indicated from an instrumented bridgewire and the bridgewire is properly short circuited, the sensor output should appropriately reduce to zero, since by definition there can be no current flow through the bridgewire. On the configurations tested it is possible that large voltages can exist from the bridgewire leads to ground with little or no potential difference across the bridgewire leads. This condition is possible if the voltages from each lead to ground are of equal amplitude and in phase. Under this condition no current will flow in the bridgewire; however, if the voltage to ground is excessive, the sensor in use will erroneously indicate bridgewire current. This phenomena manifests itself if the sensor in use exhibits insufficient common mode rejection. The sensors used have a common mode rejection of about 65 db. This means that if the ratio of the common mode voltage to bridgewire voltage (bridgewire current times bridgewire impedance) exceeds 1,800, false indication of bridgewire current occurs.

The limitation incurred by this phenomena requires that the bridgewire be perfectly shorted during each radiation test to determine the authenticity of current indications. If, when the bridgewire is shorted, the output of the VDT reduces to zero this indicates that current had been flowing in the bridgewire. If the output either does not decrease or fails to reduce to zero, this indicates the presence of excessive common mode voltage. Under this condition quantitative evaluation of data becomes difficult, however, it can be shown that the data, which contains a contribution from both bridgewire current and common mode voltage, can be adjusted to account for the common mode contribution, although this reduces the creditability of the bridgewire current data.

ABSTRACT DATA

ABSTRACT

Accession No.______________AD______________	UNCLASSIFIED
Picatinny Arsenal, Dover, New Jersey	1. Antennas
EXPERIMENTAL INVESTIGATION OF ANTENNA CHARACTERISTICS OF RANDOM LENGTH WIRES WHEN TERMINATED IN A TWO OHM LOAD	I. Experimental Investigation of Antenna Characteristics of Random Length Wires when Terminated in a Two Ohm Load
Abraham Grinoch (Coordinator)	II. Grinoch, Abraham
Technical Memorandum 1532, November 1964, 49 pp, tables, figures. UNCLASSIFIED report from the Technical Services Laboratory, Ammunition Engineering Directorate.	UNITERMS
This report describes the tests conducted on five specific wire configurations with blasting caps attached, for the purpose of determining their antenna characteristics. These configurations were formed from insulated wire similar to that furnished with M6 Blasting Caps. The five configurations were tested to determine their receiving characteristics by measuring, with suitable instrumentation, the current flowing in the bridgewire of the blasting cap as the result of electromagnetic energy abstracted by the antenna from the impinging field.	Initiators M6 Blasting caps Antennas Bridgewire Radio frequency (RF) Grinoch, A.

Accession No. ________ AD ________

Picatinny Arsenal, Dover, New Jersey

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Antennas
Bridgewire
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